

# A Warning on the GeV-TeV Connection in Blazars

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Fermi-LAT spectra at high energies (HE, 0.1-100 GeV) are often extrapolated to very high energies (VHE,  $\gtrsim 100$  GeV), and considered either a good estimate or an upper limit for the blazars intrinsic VHE spectrum. This assumption seems not well justified, neither theoretically nor observationally. Besides being often softer, observations do indicate that spectra at VHE could be also harder than at HE, even when adopting the limit of  $\Gamma \geq 1.5$ . Results based on such straightforward GeV-TeV extrapolations are in general not reliable, and should be considered with caution.

## 1. Introduction

The well-determined Fermi-LAT spectra (or Upper Limits, UL) in the MeV-GeV band for several TeV blazars are often used to derive stronger constraints on the diffuse extragalactic background light (EBL), or to constrain the distance for BL Lacs of uncertain redshift (e.g. [2, 8, 27, 29, 31]).

The underlying assumption of these studies is that the extrapolation of the Fermi-LAT spectrum to the VHE band is either a good estimate or an upper limit for the intrinsic VHE spectrum of the source, since they belong to the same hump in the spectral energy distribution (SED). The extrapolation is done either as a simple extension of the power-law (or best fit) model for the Fermi-LAT data, or using a one-zone synchrotron self-Compton model (SSC) on the overall SED.

However, the observational evidence shows that this assumption is not well justified anymore.

## 2. Blazars gamma-ray spectra

Blazars display a wide range in SED peak energies, as well as in emission components (both in time and space along the jet). The VHE band samples typically the highest energies of the emitting particle distribution, and is therefore more sensitive to even small changes in the acceleration and cooling processes. Observationally, irrespective of EBL absorption (i.e. adopting the same EBL model for all sources), the band between HE and VHE is the energy range where the spectrum of blazars typically changes the most, either because of the closeness of the SED peak or of the end of the emitting particles distribution. Therefore, the extrapolation to VHE of the HE slope is in general never a good assumption.

This is particularly true for the high-energy-peaked BL Lacs (HBL) which are bright in Fermi and have been easily detected in the first years of operation [1, 3, 4]. These are characterized by the high-energy SED peak being very close to the LAT band

(e.g. Mkn 421, Mkn 501, PKS 2155-304, PKS 2005-489, 1ES 1553+113 etc). For them, the HE and VHE bands sample the two sides of the gamma-ray hump in the SED, and thus the intrinsic VHE spectra are much softer than the HE spectra. Indeed this is the most common case among Fermi-detected HBL [10, 28].

The main question however is: can the VHE spectrum be harder than the HE spectrum? Can thus the Fermi-LAT index be used as reasonable upper limit for the hardness of the VHE spectrum, or for its luminosity? Concave HE-VHE spectra have not been observed (yet) directly. However, the observational (as well as theoretical) evidence is now showing this to be possible.

## 3. TeV spectra can be harder than GeV spectra

Let us consider three facts.

1. BL Lacs do show multiple spectral components in their synchrotron emission, which traces directly the shape of the electron distribution(s). In several cases we have already seen the superposition of two different emission components at high electron energies, with a new component emerging over a previous/steadier SED. Classical examples are given by Mkn 501 in 1997 [11, 30], 1ES 1959+650 in 2002 [25] and PKS 2155-304 in 2006 [16] (see e.g. Fig. 1). The same can thus happen in the inverse Compton emission.
2. The superposition of multiple spectral components is seen also outside specific flaring episodes, on long (months to years) timescales. One of the most evident cases was given by PKS 2005-489 in the synchrotron emission (Fig. 2), during multi-wavelength campaigns in 2004-2005. The X-ray band in 2005 became more and more dominated by a new harder emission component emerging in the SED, which probably reached its maximum in June 2009 [7].

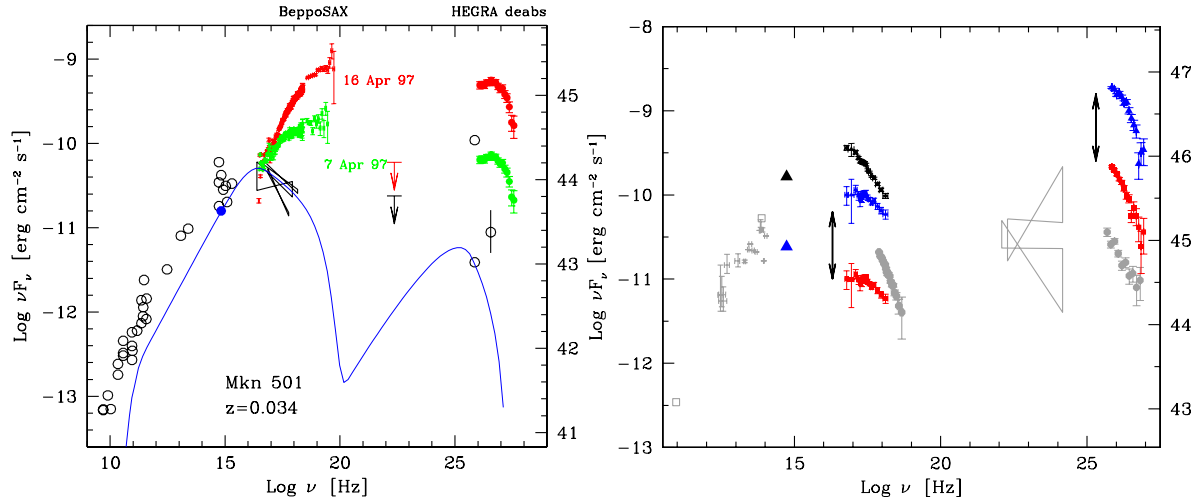


Figure 1: Examples of new emission components in the SED of blazars emerging over previous (more steadier) SEDs. Left: Mkn 501 in 1997 [11, 30]. Right: PKS 2155-304 in 2006 [16]. The peculiar spectral and timing properties of this 2006 VHE flare was interpreted as superposition of two SEDs from two different zones. The observed SED cannot be explained with a single SSC component (see [16]).

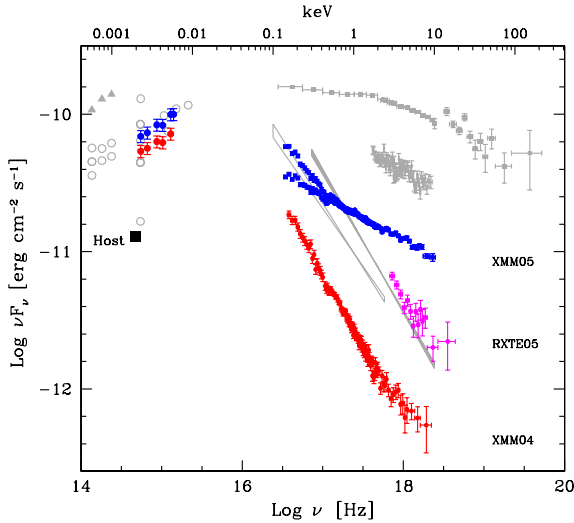


Figure 2: SED of PKS 2005-489 zoomed in the optical-X-ray band, with the opt-to X-ray data from different epochs. Blue data correspond to the XMM spectrum in 2005 corrected for two different estimates of the Galactic  $N_H$  ( $5.08$  or  $3.93 \times 10^{20} \text{ cm}^{-2}$ ). Even with the lowest Galactic column density, in 2005 the X-ray spectrum cannot be joined to the UV data from the Optical Monitor with a single smooth spectral component [9].

ical conditions in blazars which can yield TeV spectra as hard as  $\Gamma = 1.5$ , and with higher luminosity than in the synchrotron emission. Such conditions can in principle form also in specific zones of the jet, and/or in specific epochs. The overall SED of such components can easily remain hidden below a more "standard" SED and emerge or become dominant only at VHE.

Considering these three facts together, it becomes clear that spectra at VHE can very well be harder than at HE. This is true especially for those HBL where the Fermi-LAT index is closer to 2 than 1.5 (or even steeper than 2, as in IBL and LBL).

Over such a wide range of energies (5 orders of magnitude), it seems not only possible but even likely that a combination of different spectral components—either in time or from different particle populations or different emission mechanisms for the same particles—can result in *concave* overall spectra. It seems only a matter of time (and statistics) before up-turns somewhere in the overall 100 MeV – 10 TeV band are directly and significantly detected in the simultaneous gamma-ray spectrum of some blazars.

It should not be surprising, because the observational ingredients are all there. In fact, a possible example is already given by the Fermi-LAT spectrum of Mkn 501 [6], where a flaring episode has already produced a time-average HE spectrum apparently hardening towards higher energies (see Fig. 4).

Therefore, in general, Fermi-LAT spectra cannot be reliably used as UL to a) derive constraints on redshift, or b) put stronger limits on the intensity of the EBL. The results would be as weak/unreliable as their assumptions, and lead to gross over/under-estimates.

3. At VHE, intrinsic spectra as hard as  $\Gamma = 1.5 - 1.6$  are already observed, with a low EBL density (even harder in case of higher EBL densities). Classic examples are given by 1ES 1101-232 [12, 14], 1ES 0347-121 [13] and especially 1ES 0229+200 (Fig. 3), which is characterized by such hard VHE spectrum up to  $\sim 10$  TeV [15]. This demonstrates that there exist phys-

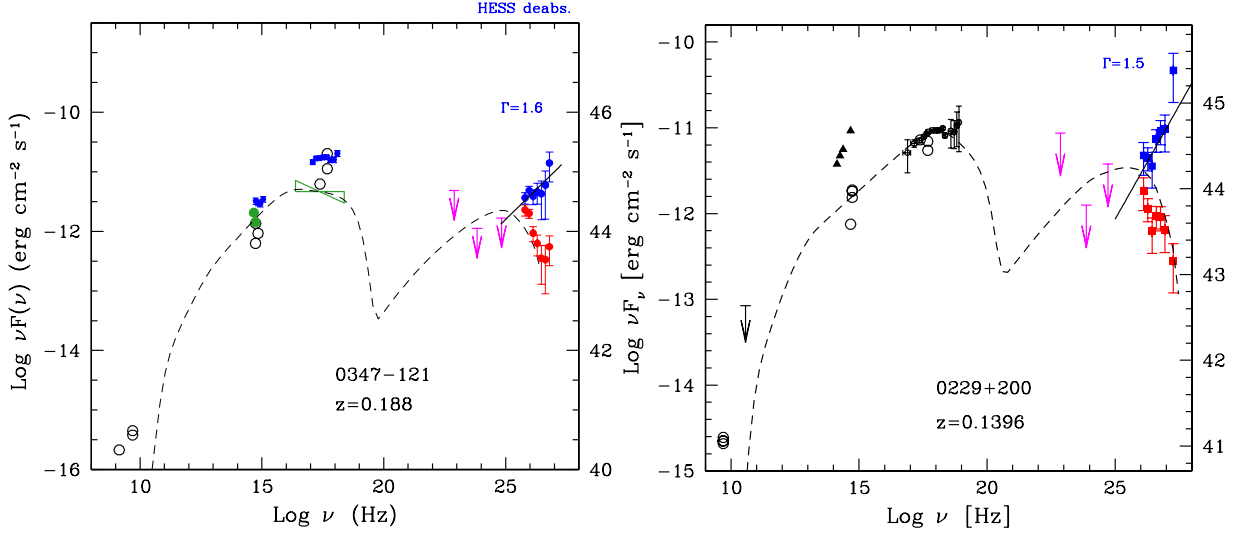


Figure 3: Examples of SED of selected HBL, characterized by hard TeV spectra with  $\Gamma \sim 1.5 - 1.6$  irrespective of the level of EBL. The absorption-corrected VHE spectra (blue points) shown here are corrected using the EBL calculations by [21] (i.e. a low EBL). Very similar results are obtained using calculations by [20, 24]. Higher levels of the EBL would make the intrinsic spectra even harder. Data and historical modeling from [4, 13, 15, 17, 18, 22].

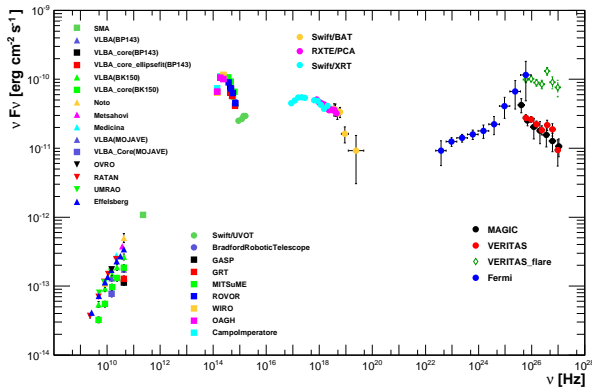


Figure 4: SED of Mkn 501 averaged over all observations taken during a multiwavelength campaign between March and August 2009 (from [6]). VHE data are corrected for EBL absorption according to [21]. The VERITAS data from a 3-day TeV flare are depicted separately in the plot.

#### 4. Consequences for EBL and blazar studies

For EBL and redshift studies, the  $\Gamma = 1.5$  limit for the intrinsic photon index is still a more robust benchmark than any Fermi-LAT extrapolation. Although it is not a “hard” limit (theoretically there are many mechanisms to obtain harder spectra, see e.g. [26]), at present it still represents the borderline between reality and speculation (for a full discussion, see e.g. [19]).

Observationally, intrinsic spectra with  $\Gamma < 1.5$  ( $\pm 0.2$ ) have never been observed so far in blazars at high electron energies (e.g.  $\gamma > 10^{3-4}$ ), neither in

the synchrotron emission nor in the inverse Compton spectrum of low-redshift sources. Photon indexes of 1.2-1 are observed at X-ray energies in high-redshift, low-energy-peaked blazars (typically FSRQ), but these appear to be explained as low-energy cutoffs in the electron distribution, if not by internal absorption [23, 32, 33]. In fact, this is a spectral feature that could in principle appear in the Fermi-LAT band for some TeV-peaked sources (i.e. those where the LAT band is deep in the valley between the two SED humps). However, it would not automatically imply a similarly hard spectrum at VHE, because in such case the VHE band would correspond to the particle distribution well above the low-energy cutoff.

At present the EBL spectrum between 0.1 and 10  $\mu\text{m}$  is constrained rather well (mostly within  $\sim 50\%$ ; [5, 12, 15]), simply by using the range of spectra observed in blazars. Any further improvement beyond that requires a prediction of the blazars’ high-energy emission at a level of accuracy which seems not (yet) at hand [19]. The uncertainty is systematic, on which model and physical conditions are actually working in blazars. For a given HE spectrum and overall SED, the range of possible VHE spectra is still large ( $\Delta\Gamma \approx 2$ ), even in a SSC scenario, depending on the choice of parameters, zones and adopted particle distributions (see e.g. [26]). And observations are demonstrating that we are still missing some fundamental aspects of the blazar physics. One-zone SSC models can work *a-posteriori*, but cannot be used reliably *a-priori* since blazars have multiple emission components, whose behaviour and interplay is still unknown. A reliable prediction of the VHE spectrum from the HE one is therefore not yet possible, at least in individual sources.

For a real progress in this field, it seems now more useful and fruitful to fix the EBL to the most consistent and likely values (e.g. [20, 21, 24]), and to focus on improving our understanding of the blazar emission properties.

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